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(54) **Method and system for producing natural gas from offshore wells.**

(57) Transporting pressure vessel means 25 are mounted on watercraft 26, and are utilized to recover raw natural gas from shut-in offshore wells. After a discrete batch of raw gas is contained within the transporting pressure vessel means, the watercraft is moved to a processing station 60, also preferably located on a platform offshore. At the processing station, liquids are separated from the natural gas, and then the natural gas is passed through a dehydrator 100 before being transported or transmitted. The invention allows recovery of natural gas from offshore wells, without the need to place processing equipment at each well. In another embodiment especially for use with ocean-located wells, a production barge 800 carrying storage pressure vessel means 804 is positioned at the well site, to which watercraft 726 are connected for loading raw natural gas.

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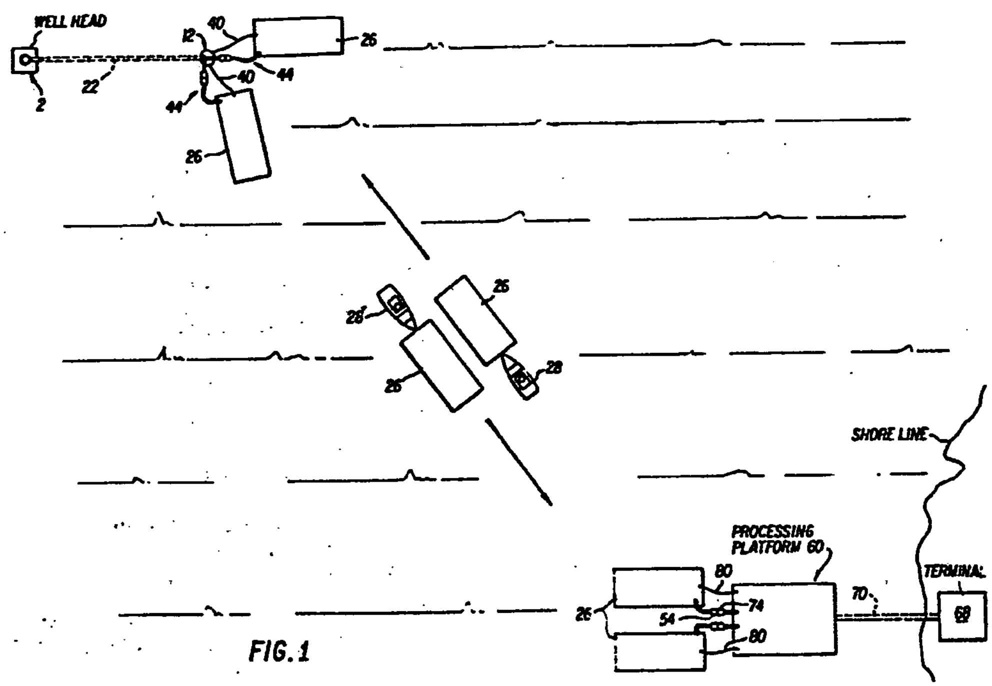

WELL HEAD
2
22
12
40
40
44
44
26
26
28
28
26
26
SHORE LINE
PROCESSING PLATFORM 60
80
74
54
80
26
70
TERMINAL
68

FIG. 1

METHOD AND SYSTEM FOR PRODUCING NATURAL GAS FROM OFFSHORE WELLS

This invention relates generally to a method and system for producing natural gas from wells located off-shore, and making it available to a terminal installation. More specifically, it relates to a method and system for producing natural gas from producible but normally shut-in offshore wells, without the need to construct a pipeline and other expensive facilities for each gas well.

For many years, wells capable of producing oil and natural gas have been drilled in offshore locations; that is, in locations located in a body of water often many miles from the nearest land. The Gulf of Mexico contains many such wells, as does the North Sea and other bodies of water around the Earth. Large numbers of existing offshore wells are capable of producing significant quantities of natural gas, and it is believed that a great many more natural gas producing wells are possible in offshore locations.

In some instances, the location and the proven natural gas production capability of offshore wells has made it technically and economically feasible to build a

pipeline and related processing facilities for each well or reservoir, so that the natural gas can be recovered and transported to a terminal facility. The terminal facility will normally be located onshore, and can be the terminus of a pipeline, an industrial plant or other large user of natural gas, a storage facility, a dock installation for loading natural gas onto ocean-going vessels, or any other type of facility to which it is desired to supply natural gas. It is also possible for a terminal facility to be located offshore, installed for example on a fixed platform to which transport ships can be docked for loading of the natural gas. Where such pipelines and related processing facilities have been constructed to serve offshore wells, subsequent recovery of natural gas from them is rather easily accomplished.

But there are large numbers of offshore natural gas producing wells or reservoirs to which pipelines cannot be built, or where on-site processing facilities cannot be installed, either because the technical difficulties are insurmountable or because the economic cost is excessive and the fiscal risk too great. These natural gas wells or reservoirs are often referred to as "producible shut-in", and are usually remote from a terminal or raw material gas processing facility or terminus. This remoteness can range from several miles, to several hundred miles for some reservoirs. In some instances, because there is now no acceptable method and system for recovering natural gas from such wells, the

natural gas is simply blown-off or flared. This, of course, results in total waste of an important energy resource.

To illustrate some of the problems involved in developing offshore natural gas wells by use of a pipeline, it is known that at present pipeline construction costs per mile in the Gulf of Mexico can easily exceed $1,000,000 per mile of pipeline. To make this cost feasible for pipeline construction, it is generally required that there be a ratio of 5 billion cubic feet of recoverable natural gas reserves per mile of pipeline. That is, a proven reservoir of at least 20 billion cubic feet of natural gas is usually necessary to justify building a four mile pipeline, for example.

But construction of the pipeline is not the only cost involved. In order to obtain the production of natural gas from offshore wells, the wells themselves must of course first be drilled. Depending upon the water depth, the formation depth, and the number of wells being drilled in the immediate area, the cost for drilling and completion of a single gas well can substantially exceed $1,000,000 per well. In addition to the drilling and completion costs, a production platform must be set on the wells in order to produce natural gas into the pipeline. On this platform natural gas is separated, dehydrated, compressed if necessary, and metered, all before entering the pipeline. Offshore platforms of this type can cost in the range of $2,500,000 to $10,000,000 each, depending

upon the number of wells served, the water depth, the size of the platform, the natural gas production rate, operating pressures, and other factors. The total investment at the well site can thus require a capital investment of $4,000,000 and beyond, to which the pipeline cost must be added.

It will be readily appreciated that unless there are reasonable prospects for obtaining extensive natural gas production from a well and sufficient users within pipeline distance of the production site to accept the produced natural gas, economic factors will dictate that the natural gas reservoir of a producible well remain shut-in, or be flared or blown-off, even if the project is technically feasible. When a few isolated wells are drilled of unproven natural gas production capacity, it is almost a foregone conclusion that any natural gas they can produce will remain shut-in, if the pipeline technique is the only available means of recovery. Even in large fields, the economic risks are often so great with the pipeline technique that known reservoirs of natural gas are simply left in a shut-in status.

In a time of worldwide energy shortage, the natural gas found in offshore shut-in wells is badly needed. The total quantity of natural gas located at present in such wells is not known with precision, but is believed to be huge. At present, for example, there are over 100 known, producible natural gas reservoirs in the Gulf of Mexico alone, all in a shut-in condition.

In several instances, extensive reserves of natural gas are known to be offshore of nations that have no onshore petroleum and which are thus forced to import oil and gas from other nations. If they were able to recover the natural gas that lies offshore in their territorial waters and make use of it, these nations could sharply reduce or eliminate their need to import energy.

As an alternative to the pipeline techniques for recovering natural gas from offshore wells, it has been proposed by the present applicants that natural gas be produced and transported from these offshore wells using the high pressure method and system described in U.S. Patent No. 4,139,019. In some instances, this approach is feasible. However, the method and system which is the subject of the noted patent still requires the building of extensive natural gas processing facilities at each reservoir site, facilities which are difficult to construct and which often cannot be economically justified, particularly for untested wells. The method and system of Patent No. 4,139,019 is thus not a satisfactory solution for recovering natural gas from large numbers of presently shut-in offshore wells.

While these and other techniques for recovering natural gas from offshore wells and reservoirs have been devised, none have yet been demonstrated to be operationally successful for the wide variety of natural gas wells and reservoirs. Thus, very large quantities of producible natural gas remain shut-in, in water locations

across the world. There is thus a great need for a new technique for recovering natural gas from shut-in offshore wells, a need which the method and system of the present invention are intended to satisfy.

Viewed from one aspect the present invention provides a method of producing natural gas from an offshore well, said well being provided with a valve assembly at the wellhead, and a loading mooring system being positioned at a distance from said wellhead and being connected by underwater supply conduit means to said wellhead valve assembly; said method including the steps of:

moving a watercraft carrying transporting pressure vessel means thereon to said offshore well;

mooring said watercraft to said loading mooring system;

connecting said transporting pressure vessel means carried by said watercraft with said wellhead valve assembly, and filling said pressure vessel means with a discrete batch of raw natural gas and any accompanying liquids to a selected pressure, said pressure vessel means being substantially empty before said filling commences;

disconnecting said transporting pressure vessel means from said wellhead valve assembly means, and then releasing said watercraft carrying said pressure vessel means from said loading mooring system;

moving said watercraft to a processing station located remote from said offshore well for final processing and handling, mooring said watercraft, and then connecting said transporting pressure vessel means carried by said watercraft with said processing station;

unloading said discrete batch of raw natural gas and any accompanying liquids into said processing station; and

processing to the extent necessary said discrete batch of raw natural gas and any accompanying liquids at said processing station, whereby to produce processed natural gas suitable for further transmission and transport.

Viewed from another aspect the invention provides a system for producing natural gas from an offshore well, said well being provided with a valve assembly at the wellhead, and said system including:

a loading mooring system spaced sufficiently from said offshore well that marine vessels can maneuver thereabout without causing damage to said wellhead valve assembly, and connected with said wellhead valve assembly by underwater supply conduit means;

a processing station located at a remote distance from said wellhead and said loading mooring system, and including means for accepting raw natural gas and any accompanying liquids and processing such to the extent necessary to produce natural gas suitable for transport and transmission;

at least two watercraft, said watercraft being movable between said loading mooring system and said processing station and each having transporting pressure vessel means mounted thereon;

said watercraft being adapted to be moored to said loading mooring system and to said processing station;

first connecting means for detachably connecting said transporting pressure vessel means on each watercraft with said wellhead valve assembly via said supply conduit means, after said watercraft is moored to said loading mooring system; and

second connecting means for detachably connecting said transporting pressure vessel means

carried by each of said watercraft with said processing station, after the watercraft has been moored thereto.

The present invention has as one of its very important features the elimination of the need to construct a permanent platform and processing facilities at the wellhead, which means that the technical difficulties and capital costs of such platform and processing facilities are all eliminated or reduced. Two other important advantages of the invention are that relatively large quantities of natural gas can be safely transported and that this transporting is economically and relatively low in cost.

In the present system, natural gas is taken from the wellhead in a raw form; that is, the natural gas may be saturated, and may have either water, oil, condensate or all present therein. The wellhead is provided only with the usual control valving and well protection arrangement, and the processing platform as required with some present natural gas recovery techniques is not needed.

The raw natural gas is loaded in the vicinity of the wellhead into transporting pressure vessel means, mounted on watercraft such as a barge or ship. In one system of the invention, a loading mooring system of known type is employed, and such is anchored some

distance from the wellhead. The wellhead is connected by a supply conduit system to the loading mooring system.

In a first embodiment of the invention, the barge or other watercraft is then secured to the loading mooring system for direct loading of the raw gas from the supply conduit system, a specifically designed connecting conduit system being employed for safely connecting the supply conduit system with the transporting pressure vessel means. The filling pressure for the transporting pressure vessel means will normally be about 2,400 p.s.i., but it can be greater or lower than this value, usually over a range between 2,000 and 3,000 p.s.i. By utilizing the loading mooring system, damage to the wellhead caused by possible collisions of the barge or other vessel with the wellhead and the equipment mounted thereon is avoided.

Preferably, the present method is carried out in all embodiments thereof so that at least one transporting pressure vessel means is connected at all times to the wellhead, to assure the maximum production of natural gas from the well. This is in accordance with the concepts described in our earlier U.S. Patent No. 4,213,476. Each pressure vessel means will typically be comprised of a plurality of storage tanks made of steel and designed to safely contain pressures in excess of 3,000 p.s.i. The steel tanks may be of forged or welded construction, and the use of other materials is possible.

Once its transporting pressure vessel means is filled, the barge or ship in the first embodiment of the invention is transported to a processing location. The processing location can be onshore or at another offshore well at which a platform and processing equipment have previously been erected, and to which a pipeline has been built. In this manner, such a platform, once built, can be adapted and used for a greatly prolonged period of time, thus significantly enhancing its cost/benefit ratio. At the processing location, the raw natural gas and any accompanying liquids are off-loaded and processed.

As has been noted, the raw natural gas will normally be saturated, and will be a mixture of natural gas, water and usually condensate. The processing location is provided with the natural gas, to dehydrate the separated natural gas and, if necessary, to compress it in preparation for transport to a terminal facility.

Each of the storage containers or tanks included in the transporting pressure vessel means may be provided with a dip tube or bottom-mounted discharge pipe, which is arranged so that the inner end thereof lies on the bottom of the storage tank or container. This dip tube allows the liquids, whether water, condensate, or a mixture thereof, to be drained first from the transporting pressure vessel means after such is connected to the processing equipment, before draining of the natural gas. The natural gas pressure within each storage

container or tank is utilized to expel the liquids through the dip tube, and drainage of the liquids continues until such have been completely removed. The natural gas is then withdrawn and processed, and the liquids are thereafter separately processed to the extent necessary and desired. This arrangement is an important preferred feature of the invention, in that it prevents any buildup of water in the storage tanks or containers. It has been discovered that water buildup in the presence of certain natural gas chemical components can damage the steel typically used to construct such containers or tanks. This essentially automates the system for always draining water and other liquids during each off-loading of natural gas and is thus an important safety feature of the invention.

One other preferred feature of the invention is that it also allows for the recovery of condensate from offshore wells, something which is not now possible when a well is shut-in. The condensate itself can be quite valuable, and its recovery by the present system is in effect a bonus.

In order to prevent the formation of hydrate ice crystals during off-loading of the natural gas from the pressure vessel means at the processing location, the invention contemplates the injection of glycol or some other hydrate inhibitor agent into the storage vessels before such are unloaded, or into the fluid flow as loading or unloading occurs, as a preferred feature.

Once the barge or other vessel has been emptied, it is returned to the well(s) being worked or produced, and may be replaced at the processing location by another watercraft. By utilizing a number of watercraft related to the production capacity of the well, the travel distances involved, and the capacities of the well and the processing equipment, it is possible in this embodiment of the invention to establish an essentially constant flow of natural gas to a processing facility, user or other terminal.

In a second embodiment of the invention, especially useful for recovering natural gas from wells or a reservoir located in the ocean perhaps two to three hundred miles from land, the individual, interconnected storage tanks or containers comprising the pressure vessel means employed to transport raw natural gas are mounted in an ocean-going ship. The loading mooring system means at the wellhead is modified by the addition of a production barge, moored permanently on site. The production barge carries a storage pressure vessel means thereon, also comprised of a plurality of interconnected, high pressure containers or tanks. A compressor is utilized on the production barge when necessary because of low well pressure, and the production barge pressure vessel means is connected with the supply conduit system and functions to collect and temporarily store raw natural gas from the well or reservoir. When wellhead pressure is high, say for example above 4,000 p.s.i., the compressor can be eliminated.

The production barge pressure vessel means functions as a storage means, to temporarily store raw natural gas while ships carrying transporting pressure vessel means are manuevered into position and connected, and during the time between when a loaded transporting ship is disconnected and the next-arriving transporting ship has been connected. Thus, the production barge makes possible a more flexible natural gas recovery method and system than the first embodiment of the present invention, one especially adapted to very remote locations in rough waters, where the connection of a ship might be delayed for several hours or longer. The storage pressure vessel means on the production barge enables natural gas production to continue even if a transporting ship is not connected to the well site mooring system, and thus continuous production of natural gas in accordance with the principles of our earlier U.S. Patent No. 4,213,476 is possible.

Returning to those developing nations that have offshore, unused natural gas reserves, the present invention can enable them to recover their own natural gas and reduce dependence upon imported energy sources. The invention offers such nations great flexibility in the use of natural gas, in that it can continuously deliver desired quantities of gas to one or more onshore users or terminal facilities.

The fact that a given nation or user may lack any onshore pipelines, or have inadequate pipeline capacity, is not necessarily a bar to the successful

recovery and utilization of natural gas by use of the present invention. The present applicants have also developed a method and system for distributing natural gas onshore in the absence of pipeline capacity, this invention being the subject of U.S. Patent No. 4,380,242. By employing the distribution method and system of Patent No. 4,380,242 with the offshore recovery method and system of the present invention, many developing nations can become partly or completely energy self-sufficient by utilizing their now untapped reserves of natural gas.

Two embodiments of the invention will now be described by way of example and with reference to the accompanying drawings, in which:-

FIG. 1 is a diagrammatic view looking down upon a body of water, and illustrating the principal elements of a first embodiment of the system of the invention as such will appear in an operational setting;

FIG. 2 is a diagrammatic, elevational view showing a typical wellhead and loading mooring system arrangement used in practising the invention, with one of the barges of FIG. 1 connected for the loading of raw natural gas;

FIG. 3 is a diagrammatic, elevational view showing a typical processing platform arrangement used in practising the invention, with one of the barges of FIG. 1 connected for off-loading of the raw natural gas;

FIG. 4 is a diagrammatic view of a processing station of the system;

FIG. 5 is an enlarged, fragmentary plan view showing a portion of the storage containers comprising one of the loading pressure vessel means carried on one of the barges of FIG. 1, and illustrating the arrangement employed to assure safe handling of the raw natural gas;

FIG. 6 is a sectional view taken generally on the line 6-6 of FIG. 5, showing the arrangement of one of the dip tubes for draining liquids from the storage container; and

FIG. 7 is a diagrammatic view looking down upon a large body of water such as an ocean, and illustrating the principal elements of a second embodiment of the invention wherein a production barge is included in the mooring system, and ships carry the pressure vessel means.

Referring now to the embodiment of FIGS. 1-6 of the drawings, a typical offshore well is indicated generally at 2, and includes a casing or conductor 4 that extends from the ocean floor 6 and projects above the surface S of the body of water. The casing or conductor 4 is supported by suitable superstructure 8, and a wellhead flow control valve assembly 10 is mounted thereon.

It should be understood that while the valve assembly 10 is shown projecting above the surface S of the body of water in FIG. 2, such might also be located below the surface. The type of wellhead installation

utilized, and whether it is above or below the water surface, will depend on a number of factors, including the depth of the water and the roughness of any expected wave action.

Positioned some distance from the well 2 is a loading mooring system 12 of generally conventional construction. The mooring system 12 includes a base 14, a buoy 16, and a cable or chain 18 which connects the buoy 16 with the base 14. The purpose for using a loading mooring system 12 is to provide a means for mooring a ship or barge at some distance from the wellhead, so that such cannot come into contact with and damage the wellhead superstructure 8 or the control valve assembly 10. Fluids flowing from the well 2 are transmitted to the buoy 16 by a supply conduit system 20, which includes an underwater supply conduit 22 connecting the wellhead control valve assembly 10 with a buoy flow control valve 24. The conduit 22 must of course be designed with flexibility as an object, so as to accommodate movements of the buoy 16, and accordingly flexible conduits and swivel joints will normally be employed.

The system of the invention utilizes transporting pressure vessel means mounted on watercraft, which can be either a barge or a self-propelled supply vessel or ship, or the like. In the first embodiment of the invention shown in FIGS. 1-6, the transporting pressure vessel

means 25 is mounted on a barge 26, several such barges being indicated at 26 in the drawings, and each being movable through the water by ocean-going tug boats 28. Each barge 26 has mounted thereon a plurality of pressure tanks or storage containers 30, which are each made of steel or other suitable material capable of safely containing a discrete batch of raw natural gas at pressures of about 3,000 p.s.i. and above. Usually, a number of storage containers or tanks 30 will be mounted on each barge 26, and such will be connected to a common manifold 32 through individual valves 34 provided with operating handles or other operating means 36, as shown in FIG. 5, to form the watercraft's transporting pressure vessel means 25. Each of the individual valves 34 includes a safety device, such as a rupture disk 38, to provide emergency pressure relief in case over pressurization or excessive temperature should occur while the associated valve 34 is closed.

The arrangement of the elements of the system in the first embodiment for loading raw gas is illustrated in FIG. 2. One of the barges 26 is moved to the loading mooring system 12, and is moored to the buoy 16 by a mooring line 40. The manifold 32 is then connected with the float flow control valve 24 through a connecting arrangement designed to ensure safe handling of the natural gas. The connecting arrangement is indicated

generally at 44, and such is like that which is described in U.S. Patent No. 4,139,019.

The connecting arrangement 44 includes one-half 46 of a connector, mounted on a conduit 48 that is connected with the flow control valve 24. A bleed valve 50 is positioned between the connector element 46 and the flow control valve 24. The barge 26 carries a flexible hose or similar conduit 52, the outer end of which carries a connector half 54 that is joinable with the connector half 46 mounted on the conduit 48. The inner end of the flexible conduit 52 is connected with the manifold 32, through a flow control valve 56. A bleed valve 58 is positioned between the connector element 54 and the flow control valve 56, and the two bleed valves 50 and 58 are employed to relieve pressure on the coupled elements 46 and 54, respectively, before such are opened.

The amount of natural gas vented by the two bleed valves 50 and 58 can be relatively large, and could pose a hazard to personnel on the watercraft. To avoid what might otherwise be a safety problem, the outlets of the bleed valves 50 and 58 respectively have lengthy vent or flare pipes 51 and 59 connected thereto, of sufficient length to carry discharged natural gas a safe distance away.

Initially, the containers or tanks 30 comprising the transporting pressure vessel means 25 on a barge 26 are all essentially empty. It has been proposed by others that such containers or tanks initially carry water or another liquid, which is then displaced by inflowing natural gas. The present invention specifically avoids this concept, and accordingly, liquid pumping and handling equipment, and the liquid itself, are not needed. This contributes to the simplicity and economy of the present invention. Further, the absence of water in containers or tanks 30 made of steel also contributes to their safety when handling natural gas at high pressure of from 2,000 to 3,000 p.s.i.

When water is carried in containers or tanks 30 made of steel and becomes mixed with constituents of natural gas, it has been found that corrosive substances can be formed which will damage the steel, sometimes to the point where failure under pressure can result. This problem can become more acute when water is routinely carried in the containers or tanks, as in the displacement natural gas handling system just mentioned. Over time, repeatedly transported water can become laden with impurities, significantly increasing the safety hazard. This whole problem is minimized in the present method by having the containers or tanks 30 essentially empty before natural gas is placed in them, and by not transporting them with water therein between carrying loads of natural gas.

In some instances when practising the present invention it will be necessary to transport raw natural gas containing water. The present system includes a dip tube arrangement that assures removal of any such water during off-loading of the raw natural gas, and this arrangement will later be described in detail. By thus removing water from the containers or tanks 30 during off-loading they are made empty for the return trip to the wellhead, and any hazard to them is minimized.

The pressure tanks or containers 30 of the pressure vessel means 25 on a barge 26 secured to the loading mooring system 12 are filled with raw natural gas from the well 2, the raw natural gas normally flowing under high pressure from the well. The loading is continued until the transporting pressure vessel means 25 contains a discrete batch of the raw gas, preferably at a pressure of about 2,400 p.s.i. Then, loading is terminated, and the flow of raw natural gas is switched to another barge 26.

In order to assure maximum production from a gas well 2, it is preferable that the flow therefrom be continuous at a preselected rate chosen to correspond to the characteristics of the well, as is set forth in our earlier U.S. Patent No. 4,213,476. It is to be understood that the system elements required for such continuous production, as described in said patent, can be

utilized in the arrangement of FIG. 2, with suitable modifications. As presented, FIG. 2 shows the most elemental system for handling the raw natural gas.

The barges 26 are shuttled between the well 2 and a processing platform 60 by use of the tug boats 28. The processing platform 60 has a processing station constructed thereon, indicated generally at 62. The number of barges 26 employed with the invention is chosen so that preferably there will always be a barge 26 connected to the loading mooring system 12 for receiving raw natural gas from the well 2. Obviously, given this goal, factors such as the capacity of the pressure vessel means on each barge, the distance to be traveled, the production rate of the gas well, and the processing platform 60 will all need to be taken into account to select the number of barges 26 and tug boats 28 required for a given production situation.

Turning now to FIGS. 1, 3 and 4, the processing platform 60 in the system is preferably located offshore, and includes an elevated platform 64 mounted on caissons or legs 66 projecting above the ocean floor 6. The platform 60 is preferably one which has already been built in connection with an earlier well or reservoir, and is shown connected with an onshore terminal facility 68 by a pipeline 70. However, in some instances it may be both desirable and feasible, particularly for new fields

about to be developed, to build a platform 60 especially for practicing the present invention. In any event, one such platform may service several different wells, which greatly reduces costs over prior production methods and systems.

It must also be noted that in some instances the processing station 62, which is shown mounted on the platform 60 in the drawings, might instead be located onshore, at a location where the barges 26 can be docked. Usually, however, an offshore arrangement is preferable, to assure easy handling of the barges, and to take advantage of platforms already in place.

It should also be noted that the presence of the pipeline 70 is not absolutely required, even though this arrangement is preferable in most instances. An alternative arrangement is to move the processed natural gas from the processing station 62 by the technique described in U.S. Patent No. 4,139,019, or even by the refrigerated technique described in U.S. Patent No. 3,232,725. But in those instances wherein a pipeline has already been built to service an offshore platform which is already in place, the economics will normally dictate that such be utilized instead of ship transport of the processed natural gas.

The processing station 62 includes an inlet line 72, to which the connector element 54 is connectible through a connector half 74, a flow control valve 76, and a bleed valve 78, the bleed valve 78 having a vent or flare pipe 79 connected to its outlet to assure safe discharge of vented natural gas. A barge 26 is moved to the platform 60 by a tug boat 28, and then is moored thereto by a mooring cable 80. Thereafter, the connector elements 54 and 74 are joined, and everything is in readiness for processing of the raw natural gas.

The raw natural gas may be saturated, and will normally contain water, crude oil, or condensate, or a mixture thereof. In processing, the liquid must be removed from the mixture. In addition, it has been found that the natural gas should be as devoid of water and water vapor as possible before it is placed in a pipeline for transmission to a user. Further, as described earlier, in the present method the desire is to remove all water from steel tanks or containers 30 during off-loading.

The liquid is removed from the raw natural gas in the invention by a unique arrangement, employing a dip tube as illustrated in FIG. 6, or a similar arrangement. Each of the pressure storage tanks or containers 30 is provided with a threaded neck 82, or like arrangement, for mounting the body of the valve 34 therein. Secured to the inlet of the valve 34 is a dip tube 84, of sufficient length so that the outer end thereof is in engagement with the bottom of the pressure vessel. The

dip tube 84 functions to collect and transmit any liquids present within its container or tank 30, as the first occurrence after the valve 34 is opened.

This transmission of liquids, as the first occurrence after opening of the valve 34, occurs in this manner. After the raw gas enters the container or tank 30, the liquids will separate out and settle on the bottom, where the end of the dip tube 84 rests. The natural gas will be above the liquids and under high pressure. When the valve 34 is opened, the high pressure natural gas will drive the liquids through the dip tube 84, until essentially all of the liquids have been drained. Only then will the dip tube 84 be open to receive the natural gas.

Taking advantage of the operational characteristics of the dip tube 84, the processing station includes a liquid reservoir 85, a gas/liquid separator 88, and a pair of flow control valves 90 and 92, associated with the liquid reservoir 86 and the separator 88 respectively. Initially upon opening of the flow control valve 76, the flow control valve 92 will be closed and the flow control valve 90 opened, so that the liquids driven through the dip tube 84 will directly enter the reservoir 86. As the liquids in the pressure vessel means near depletion, the valve 90 is closed, and valve 92 opened. Thereafter, the separator 88, which is connected by a conduit 94 to the liquid reservoir 86, functions in the usual manner to remove any remaining liquids from the raw natural gas.

Obviously, if desired, the separator 86 can be relied upon alone to separate the liquids from the initiation of flow into the processing station 62. Further, other types of liquid and natural gas separation arrangements are also possible. The important thing, from the standpoint of the invention, is to provide for the separation of the liquids from the natural gas, as the raw gas flows from the pressure vessel means to the processing station.

The separated liquids are periodically removed from the reservoir 86 through a conduit 96 and valve 98. Obviously, the conduit 96 could be connected to a separate pipeline, if desired. Considerable quantities of valuable condensate can be obtained from the raw gas, which contributes to a more favorable cost/benefit relationship for the system.

A dehydrator 100 is positioned after the separator 88 for drying the separated natural gas. The natural gas is then ready for transmission or transport. Usually, it will be placed in the pipeline 70.

Depending upon operating conditions, the processed natural gas may or may not need compression before entering the pipeline 70. Referring again to FIG. 4, a compressor is indicated at 102 provided with a bypass line 104 having valve 106 therein. Close-off valves 108 are also provided at each side of the compressor 102. If compression is needed, the bypass valve 106 is closed, and the valves 108 are opened to

allow flow through the compressor 102. When the natural gas is under sufficient pressure coming from the dehydrator 100, the bypass valve 106 is opened, and the valves 108 are closed.

The processing station 62 as shown in FIG. 4 also includes a meter 110 to measure the quantity of natural gas transmitted through the pipeline 70. The location for such a meter is of course a matter of choice and, indeed in some instances, it can be eliminated altogether. A main flow control valve 112 controls flow into the pipeline 70.

It can happen that hydrate ice crystals will form during off-loading of the natural gas into the processing station 62. It has been found this problem can be alleviated by injecting a hydrate inhibitor agent into the raw gas, such as glycol. If desired, the agent can be placed directly into the storage containers or vessels 30, to mix with the raw gas as it flows into the processing station 62, and such is illustrated in FIG. 4.

Referring again to FIG. 4, a reservoir for glycol or other hydrate inhibitor agent is indicated at 114, and such is connected to the inlet conduit 72 by a conduit 116 having a metering valve 118 therein. The valve 118 is adjustable to provide for the desired rate of flow of the glycol or hydrate inhibitor agent into the raw gas.

Turning now to FIG. 7, a second embodiment of the present invention is shown diagrammatically therein,

wherein a plurality of ocean-going ships 726_A through 726_D are employed to transport the natural gas from an offshore gas well 702 to a facility 760 located at a port facility P, the facility 760 being designed to accomplish final processing and handling of the gas. The gas well 702 has a loading mooring system 712 located a distance therefrom, and is connected thereto by a supply conduit system 722, the loading mooring system 712 being similar to that in FIGS. 1-6 except that it includes a production barge 800 secured by a mooring line 740 to the float 716 of the mooring system.

The production barge 800 remains moored at the well site, and includes a plurality of individual, interconnected high pressure containers or tanks 802 that together define a storage pressure vessel means 804, connected by conduit means 806 to the outlet of a compressor 808. The inlet of the compressor 808 is connected by a conduit 810 to the supply conduit system 722, for receiving raw natural gas from the gas well 702.

The transporting ships 726_A through 726_D are essentially identical in construction, and correspond to the barges 26 of FIGS. 1-6. Each of the transporting ships 726_A through 726_D carries a transporting pressure vessel means 725 thereon, comprised of a plurality of interconnected, individual high pressure tanks or containers 730, connected by a manifold arrangement like that associated with the tanks 30 in FIGS. 1-6. The ships 726_A and 726_D are connectible to a boom assembly

812 carried on the production barge 800, for the loading of natural gas into the transporting pressure vessel means 725. A conduit 814 is employed to connect the storage pressure vessel means 804 with the transporting pressure vessel means 725, and is arranged to function like the conduit system 44 in FIGS. 1-6. While for purposes of clarity the conduit 814 is shown separate from the boom assembly 812 in FIG.7, it is to be understood that in actual practice the conduit elements will be incorporated into the boom assembly to provide easy, safe connection and disconnection.

The method and system of FIG. 7 functions similar to that of FIGS. 1-6, except for the role of the production barge 800. The barge 800 receives the raw natural gas produced from the gas well 702, which is accumulated and stored in the storage pressure vessel means 804 during the time when a transporting ship 726_A through 726_D is not connected to the barge. This feature permits continuous production from the gas well 702 in accordance with the principles set forth in our earlier U.S. Patent No. 4,213,476, even in the absence of a transporting ship. Thus, should the return of a transporting ship 726_A through 726_D be delayed for several hours or more, or if rough seas temporarily prevent a ship from being connected with the storage barge 800, natural gas production can continue. Further, the production barge 800 mounts a single compressor apparatus 808 to compress raw natural gas for loading, rather than

requiring the permanent installation of such a compressor apparatus at the well site, or the provision of a compressor on each of the transporting ships 726_A through 726_D. Additional initial processing equipment could also be located on the production barge 800, as will be discussed later.

It should be understood that in some instances raw natural gas coming from a gas well may have a pressure sufficiently high such that the compressor 808 is not required. In such an instance, it is either removed from the production barge 800, or simply bypassed.

In the embodiment of the invention shown in FIG. 7, one of the transporting ships, say the ship 726_A, is connected to the production barge 800 by the boom assembly 812, and the conduit arrangement 814 is coupled and placed in operation. The transporting pressure vessel means 725 then receives raw natural gas from the gas well 702 via the supply conduit 722 and the storage pressure vessel means 804, the individual container or tanks 802 of the latter being fitted with a dip tube arrangement like that shown in FIG. 6 and preferably being emptied during each loading operation into a transporting ship 726_A through 726_D. When loading of the ship 726_A is complete, it is disconnected from the boom assembly 812 and moves away therefrom. From the time of disconnection of the transporting ship, the storage pressure vessel means 804 continues to receive and store raw natural gas.

The transporting ship 726_D then replaces the transporting ship 726_A at the production barge 800, while

the ship 726_A follows the loaded ship 726_B to the port P, which may be several hundred miles away.

While the ships 726_A and 726_B are in transit to the port B, the transporting ship 726_C is being unloaded, after which it will follow the empty ship 726_D back to the production barge 800. The port P is preferably designed so that it has two ship berths 820 and 822, each including an off-loading boom assembly 824 or 826 that is connected by an off-loading conduit 828 or 830 through a flow control valve 832 or 834, respectively, to a pipeline 836 leading to equipment for effecting final processing and handling of the raw natural gas. The equipment (not shown) of the processing facility or station 760 of FIG. 7 will normally be similar to that shown in FIG. 4, except that in FIG. 7 it is mounted on land. It is to be understood that, if it is so desired, an offshore processing station like that shown in FIG. 3 could be employed in FIG. 7, in place of an on-land processing station; in this arrangement, the ships 726_A through 726_D would be moored to the offshore platform for off-loading. Each of the off-loading boom assemblies 824 and 826 will incorporate conduit arrangements for connecting in a safe manner with the transporting pressure vessel means 725, the conduit arrangements being like those shown in FIG. 3.

Although four transporting ships 726_A through 726_D are shown in FIG. 7, it is to be understood that the number can be varied, and will depend upon actual operating conditions. Among the factors to be taken into

account will be the holding capacity of each pressure vessel means 725, the distance from the gas well or reservoir to the processing facility 760, the production rate of the gas well 702, the speed of the ships, and other factors. The following example will serve to illustrate how the components of an actual system in accordance with FIG. 7 might be selected:

Factors Assumed:

Distance from wellhead 702 to port P	200$\pm$ nautical miles
Flowrate of well 702	40,000 mcf/day
Well Flowing pressure	150 p.s.i.

System Components:

Number of transporting ships required, assuming transporting pressure vessel means capacity of 30,000 mscf, and an average ship speed of 14 knots	4 ships
Horsepower load for the compressor 808 on the production barge 800, to achieve 2,400 p.s.i. in the pressure vessel means 725	6,600 hp

Obviously, any significant variation in ship speed or the holding capacity of the pressure vessel means 725 would produce a different set of system components, assuming the transport of the same volume of natural gas. The techniques for selecting the specific components for a selected job will be readily understood from the example just given.

Typically, the individual tanks or containers 730 will be placed vertically in the holds of the transporting ships 726_A through 726_D, mounted in appropriate racks and interconnected by a manifold arrangement.

Each tank or container 730 should be capable of safely transporting the raw natural gas at a pressure of about 3,000 p.s.i. or greater. Usually, the transporting pressure will be about 2,400 p.s.i., because at about this pressure a phenomena known as supercompressability is present for natural gas. When supercompressability is present, the amount of natural gas than can be carried increases substantially, which is an important reason for selecting an operating pressure between 2,000 and 3,000 p.s.i., in addition to the fact that these pressures enable a large quantity of natural gas to be transported to maximize the cost/benefit ratio of the invention.

In a typical installation, one hundred of the tanks or containers 730 will be placed on a single ship, substantially more than employed on the barges 26 of FIGS. 1-6. The containers or tanks 30 and 730 will be essentially identical in size and construction, however, for most installations. Because of their larger number of tanks or containers, the ships of FIG. 7 will obviously be able to transport much more natural gas per trip than the barges of FIGS. 1-6, which makes them more suitable for long distance operations, say over 100 miles.

To summarize the invention, it is first necessary to identify the terminal facility to which natural gas is to be transported, and to then determine the amount required and the necessary delivery schedule. Suitable offshore wells are then identified, which must have an adequate production capacity. The quality and

content of the raw natural gas is then determined, after which the steps of the present method are undertaken. The present method includes as a first step the establishment of a processing station, of a design to effect necessary processing of the raw natural gas and produce finished gas suitable for the intended use. Normally, this processing station or facility will be far remote from the well or reservoir area, located on an offshore platform as in FIGS. 1-6 or onshore as in FIG. 7, and will also effect final handling of the natural gas before it is placed in a pipeline or otherwise distributed. Then, a watercraft with essentially empty pressure vessel means thereon is moved to the offshore well, and the pressure vessel means is connected through a mooring system with the wellhead. This connection is made directly to the supply conduit system 20 in the first embodiment of FIGS. 1-6, and indirectly through the production barge 800 in the embodiment of FIG. 7. The pressure vessel means is then filled with a discrete batch of raw natural gas, which can contain both gas and liquids. After filling is complete, the watercraft is moved to the processing station, and the pressure vessl means is connected to the processing equipment.

At the processing station, any liquids present therein are first removed from the raw gas. Then, the natural gas is normally passed through a dehydrator, and is ready for transmission or transport to a terminal. Preferably, the raw natural gas is passed through a

conventional liquid/gas separator before being passed through the dehydrator. In addition, if the pressure of the processed natural gas is insufficient after passing through the dehydrator, it is compressed before transport or transmission.

In most instances, the working pressure of the processing station will be significantly below the pressure of the raw natural gas in the pressure vessel means. Under these conditions, the raw gas will flow freely through the processing station. If the pressure differential is not sufficient, however, it may prove necessary or desirable to install scavenger compressors on the processing station to ensure adequate removal of the raw gas from the pressure vessel means.

The present invention requires only one processing station to effect final processing and handling of the natural gas. Further, it makes it possible to make more extensive use of both existing and newly built offshore platforms and equipment, allowing a greater cost recovery factor therefrom. The present method is adaptable to substantially any offshore well, where a minimal amount of natural gas is to be found for supporting the minimal recovery costs which the invention entails.

Returning to an important feature of the invention mentioned earlier, it is again noted that the raw natural gas in the present system is carried in the pressure vessel means under high pressure, and without

the need for refrigeration equipment of the kind proposed by others. This makes the transporting watercraft lighter and able to carry a larger load of natural gas, and reduces both initial equipment cost and operational costs.

Further, it is again noted that the pressure vessel means on the transporting watercraft is essentially emptied at the processing facility, so that any residual pressure will be very low compared to the operating pressure of between 2,000 and 3,000 p.s.i. This will assure that a maximum load of natural gas can be carried. In addition, the loading process advocated by others wherein water or another liquid is initially contained in some or all of the individual containers or tanks of the pressure vessel system before they are filled with natural gas is completely avoided in the present method and system, as both unnecessary, and a potential safety hazard because of possible damage to steel containers or tanks resulting from chemical reaction between water and constituents of natural gas. By not adopting this loading process and its related off-loading process, the necessity to trasnport water and have it available at the well site is avoided, as is the need for and cost of liquid pumps and other handling equipment.

Returning to the arrangement for mooring the barge or other watercraft to the processing platform, for purposes of simplicity FIGS. 1-6 show the barge 26 to be moored directly to the platform 60. In practice, however, this arrangement would only be suitable for sheltered,

calm waters, where wave and tidal action is at a minimum. Normally, it will be necessary to employ the same type of mooring system at the processing platform 60 as is shown for the wellhead in FIGS. 1-6, to avoid possible damage to either the barge or the platform.

Because an off-loading mooring system for use with the processing platform 60 would be identical to that shown in FIGS. 1-6 for use with the wellhead, such is not illustrated in the drawings. In an actual installation, an off-loading mooring system would simply be stationed at a distance from the platform 60, and would be connected thereto by an underwater conduit system. The connector element arrangement on the processing platform 60 would of course need to be modified to include a suitable length of flexible conduit. The operational aspects of such an arrangement correspond to those for the illustrated wellhead arrangement of FIGS. 1-6.

The unique arrangement of FIG. 7, with its production barge 800, makes possible another variation on locating natural gas processing equipment. For some applications, it may be desirable to locate equipment components of the processing station shown in FIGS. 3 and 4 on the production barge 800, preferably before the storage pressure vessel means 804. This can be desirable, for example, when the raw natural gas is of high quality. Among the components that could in some instances be located on the production barge 800 are the separator 88, the dehydrator 100, and the reservoir 114 and its related

equipment for placing an inhibitor agent into the natural gas. When such equipment is located on the production barge 800, the remotely located processing station to which the natural gas is transported for final processing and handling can be simplified, in the ultimate case to no more than a natural gas receiving facility for transfering the gas to a pipeline, or to transport vehicles in accordance with the distribution method and systems of United States Patent No. 4,380,242. When a liquid/gas separator 88 is employed on the production barge 800, the ships 726_A through 726_D should carry containers for taking off the separated liquids. No drawing figure is believed necessary to show these variations, since their construction and operation is apparent from FIGS. 1-7.

Obviously, many variations and modifications of the invention are possible.

CLAIMS:

1. A method of producing natural gas from an offshore well, said well being provided with a valve assembly at the wellhead, and a loading mooring system being positioned at a distance from said wellhead and being connected by underwater supply conduit means to said wellhead valve assembly, said method including the steps of:

moving a watercraft carrying transporting pressure vessel means thereon to said offshore well;

mooring said watercraft to said loading mooring system;

connecting said transporting pressure vessel means carried by said watercraft with said wellhead valve assembly, and filling said pressure vessel means with a discrete batch of raw natural gas and any accompanying liquids to a selected pressure, said pressure vessel means being substantially empty before said filling commences;

disconnecting said transporting pressure vessel means from said wellhead valve assembly means, and then releasing said watercraft carrying said pressure vessel means from said loading mooring system;

moving said watercraft to a processing station located remote from said offshore well for final processing and handling, mooring said watercraft, and then connecting said transporting pressure vessel means carried by said watercraft with said processing station;

unloading said discrete batch of raw natural gas and any accompanying liquids into said processing

station; and

processing to the extent necessary said discrete batch of raw natural gas and any accompanying liquids at said processing station, whereby to produce processed natural gas suitable for further transmission and transport.

2. A method as claimed in claim 1, wherein said unloading step includes:

first draining any liquids from said transporting pressure vessel means, after which said natural gas is unloaded, the gas then being passed through a liquid/gas separator.

3. A method as claimed in claim 1 or 2, wherein said processing station is located offshore, and including additionally the step of:

transmitting said processed natural gas onshore from said processing station by a pipeline.

4. A method as claimed in claim 3, including additionally the step of:

compressing said processed natural gas to a desired pressure, if it is not already at such pressure, before passing the processed natural gas through said pipeline.

5. A method as claimed in claim 3 or 4, including additionally the step of:

metering said processed natural gas before passing it through said pipeline.

6. A method as claimed in any preceding claim, wherein said transporting pressure vessel means is directly connected with said wellhead valve assembly

and is directly filled with raw natural gas, and wherein said processing station is located offshore, and said watercraft is moored to an off-loading mooring system positioned near to and connected by underwater conduit means with said offshore processing station.

7. A method as claimed in any of claims 1 to 5, wherein said loading mooring system includes a production barge located at the gas well and carrying storage pressure vessel means thereon connected to receive raw natural gas from the gas well;

said watercraft being moored to the production barge of said loading mooring system, and being connected with said storage pressure vessel means to receive raw natural gas therefrom during filling of said transporting pressure vessel means; and

wherein said method includes the further step of storing raw natural gas in said storage pressure vessel means on said production barge when the transporting pressure vessel means of a watercraft is not connected with said storage pressure vessel means.

8. A method as claimed in claim 7, wherein the step of filling said transporting pressure vessel means from said storage pressure vessel means includes:

first draining any liquids from said storage pressure vessel means, into said transporting pressure vessel means.

9. A method as claimed in claim 7 or 8, wherein said production barge includes a compressor connected between said gas well and said storage pressure vessel means, and wherein said method includes the additional step of:

compressing said raw natural gas before it is placed in said storage pressure vessel means.

10. A method as claimed in any of claims 7 to 9, wherein said production barge includes a separator means between said gas well and said storage pressure vessel means, and wherein said method includes the additional step of:

separating any liquids from the raw natural gas before such enters said storage pressure vessel means.

11. A method as claimed in any of claims 7 to 10, wherein said production barge includes a dehydrator means, and wherein said method includes the additional step of:

dehydrating the raw natural gas before it is placed in said transporting pressure vessel means.

12. A system for producing natural gas from an offshore well, said well being provided with a valve assembly at the wellhead, and said system including:

a loading mooring system spaced sufficiently from said offshore well that marine vessels can maneuver

thereabout without causing damage to said wellhead valve assembly, and connected with said wellhead valve assembly by underwater supply conduit means;

a processing station located at a remote distance from said wellhead and said loading mooring system, and including means for accepting raw natural gas and any accompanying liquids and processing such to the extent necessary to produce natural gas suitable for transport and transmission;

at least two watercraft, said watercraft being movable between said loading mooring system and said processing station and each having transporting pressure vessel means mounted thereon;

said watercraft being adapted to be moored to said loading mooring system and to said processing station;

first connecting means for detachably connecting said transporting pressure vessel means on each watercraft with said wellhead valve assembly via said supply conduit means, after said watercraft via moored to said loading mooring system; and

second connecting means for detachably connecting said transporting pressure vessel means carried by each of said watercraft with said processing station, after the watercraft has been moored thereto.

13. A system as claimed in claim 12, wherein said transporting pressure vessel means includes:

a plurality of interconnected high pressure containers;

valve means arranged to be opened and closed, and connectible with said wellhead valve assembly by said first connecting means, and with said processing station by said second connecting means; and

dip tube means within each of said high pressure containers, one end of said dip tube means being connected with said valve means, and the other end thereof engaging the bottom of its associated container;

whereby when said transporting pressure vessel means valve means is connected with said processing station by said second connecting means and is opened in the presence of a discrete batch of raw natural gas disposed within said pressure vessel means under pressure, the pressure of the natural gas will act on any liquids contained in said raw gas to first force said liquids to discharge through said dip tube, before the discharge of the natural gas.

14. A system as claimed in claim 12 or 13, wherein said first connecting means includes:

a flow control valve, a bleed valve, and one-half of a connector mounted on said loading mooring system,

arranged in series moving outwardly from said supply conduit means; and

a flow control valve, a bleed valve, and the other one-half of a connector mounted on said transporting pressure vessel means, arranged in series moving outwardly from said pressure vessel means valve means.

15. A system as claimed in any of claims 12 to 14, wherein said processing station is located off-shore, and including additionally:

an off-loading mooring system spaced from said processing station a distance sufficient to allow marine vessels to maneuver thereabout without causing damage to said station;

underwater conduit means connecting said off-loading mooring system with said processing station; and

said second connecting means incorporating said underwater conduit means.

16. A system as claimed in any of claims 12 to 15, wherein said loading mooring system includes:

buoy means connected with said wellhead valve assembly by said underwater supply conduit means; and

production barge means connected with said buoy means, and having storage pressure vessel means thereon, connected with said underwater supply conduit means;

said first connecting means being connectible with said storage pressure vessel means on said production barge means, whereby said transporting pressure vessel means receives raw natural gas from said gas well through said storage pressure vessel means, said storage pressure vessel means receiving raw natural gas from said well and storing such when a transporting pressure vessel means is not connected thereto.

17. A system as claimed in claim 16, wherein said production barge means has a compressor thereon, connected between said underwater supply conduit means and said storage pressure vessel means.

18. A system as claimed in claim 16 or 17, wherein said storage pressure vessel means includes;

a plurality of interconnected high pressure containers; and

dip tube means within each of said high pressure containers of said storage pressure vessel means, arranged so that when said storage pressure vessel means is connected with said transporting pressure vessel means by said first connecting means, any liquids contained within said storage pressure vessel means will be discharged into said transporting pressure vessel means, before the discharge of natural gas thereinto.

19. A system as claimed in any of claims 16 to 18, wherein said production barge means carries thereon equipment for processing raw natural gas, before such is loaded into transporting pressure vessel means connected thereto.

20. A system as claimed in any of claims 12 to 19, wherein said processing station includes:

means for separating any liquids from said raw natural gas;

dehydrator means positioned after said liquid separation means, constructed and arranged to lower the moisture content of the natural gas to an acceptable level for pipeline transmission; and

compressor means located after said dehydrator means, for raising the pressure of the processed natural gas to a selected pressure, if the processed natural gas is not already at that selected pressure.

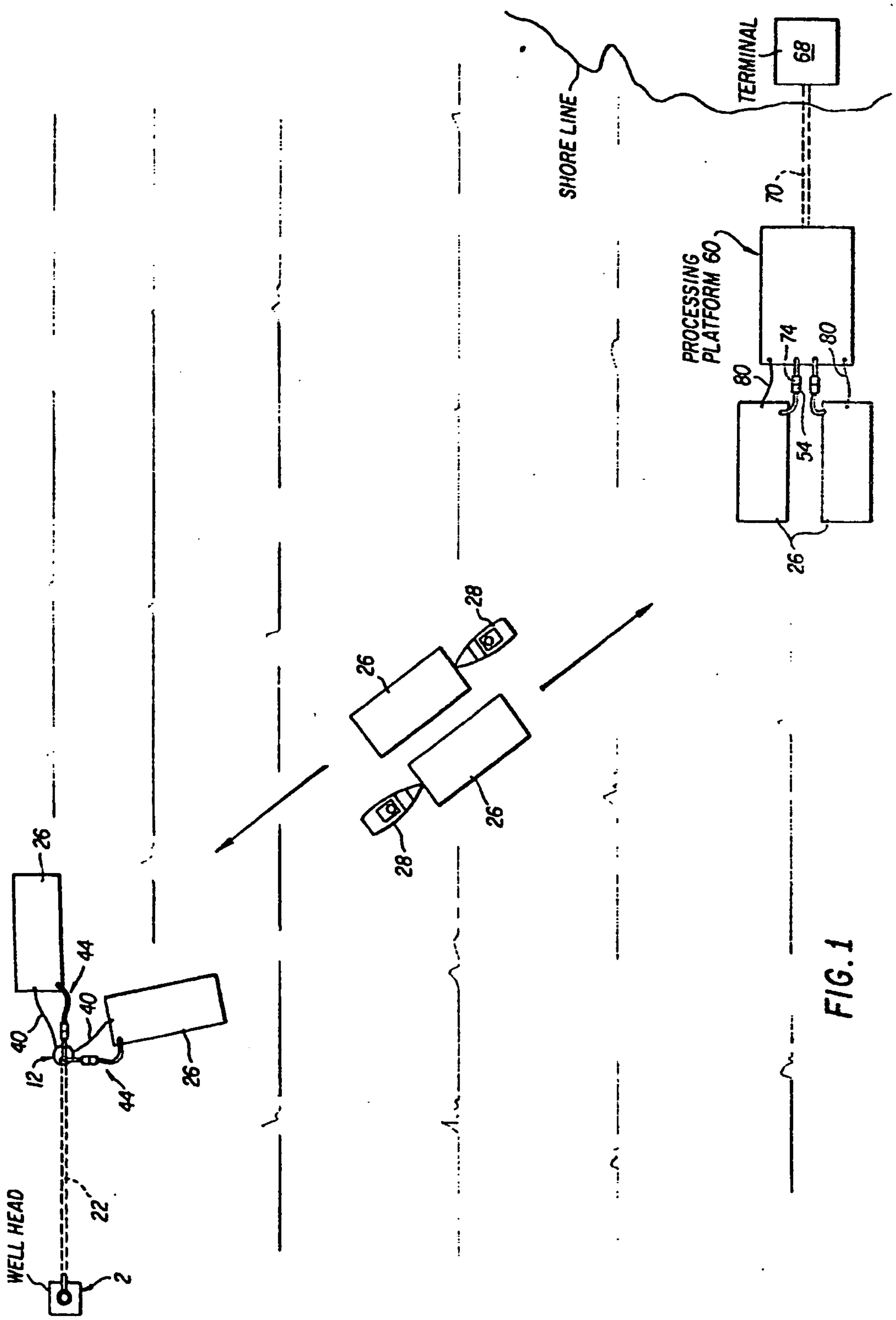
WELL HEAD
2
22
12
40
44
26
28
SHORE LINE
TERMINAL
68
70
PROCESSING PLATFORM 60
74
80
54

FIG. 1

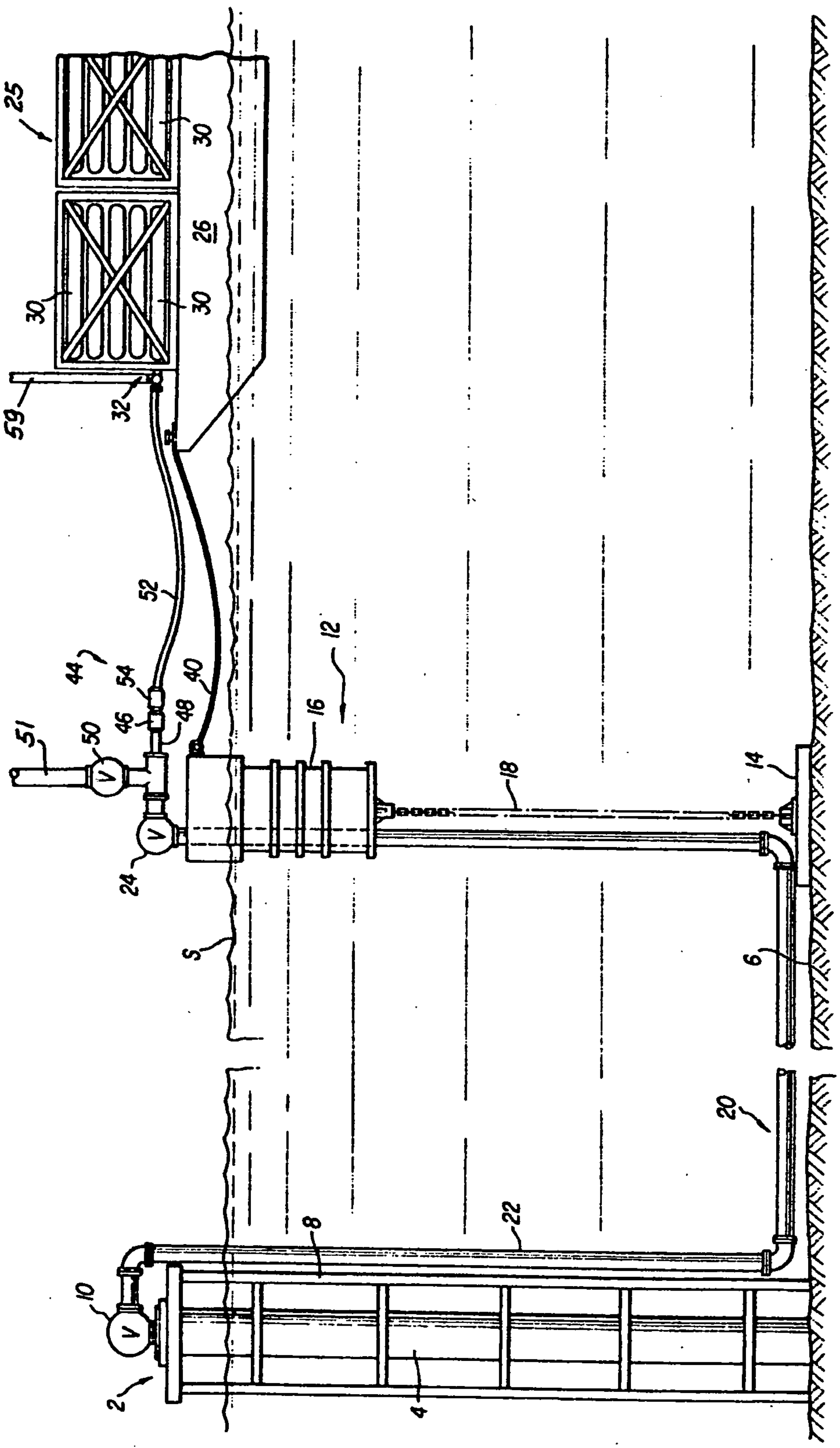
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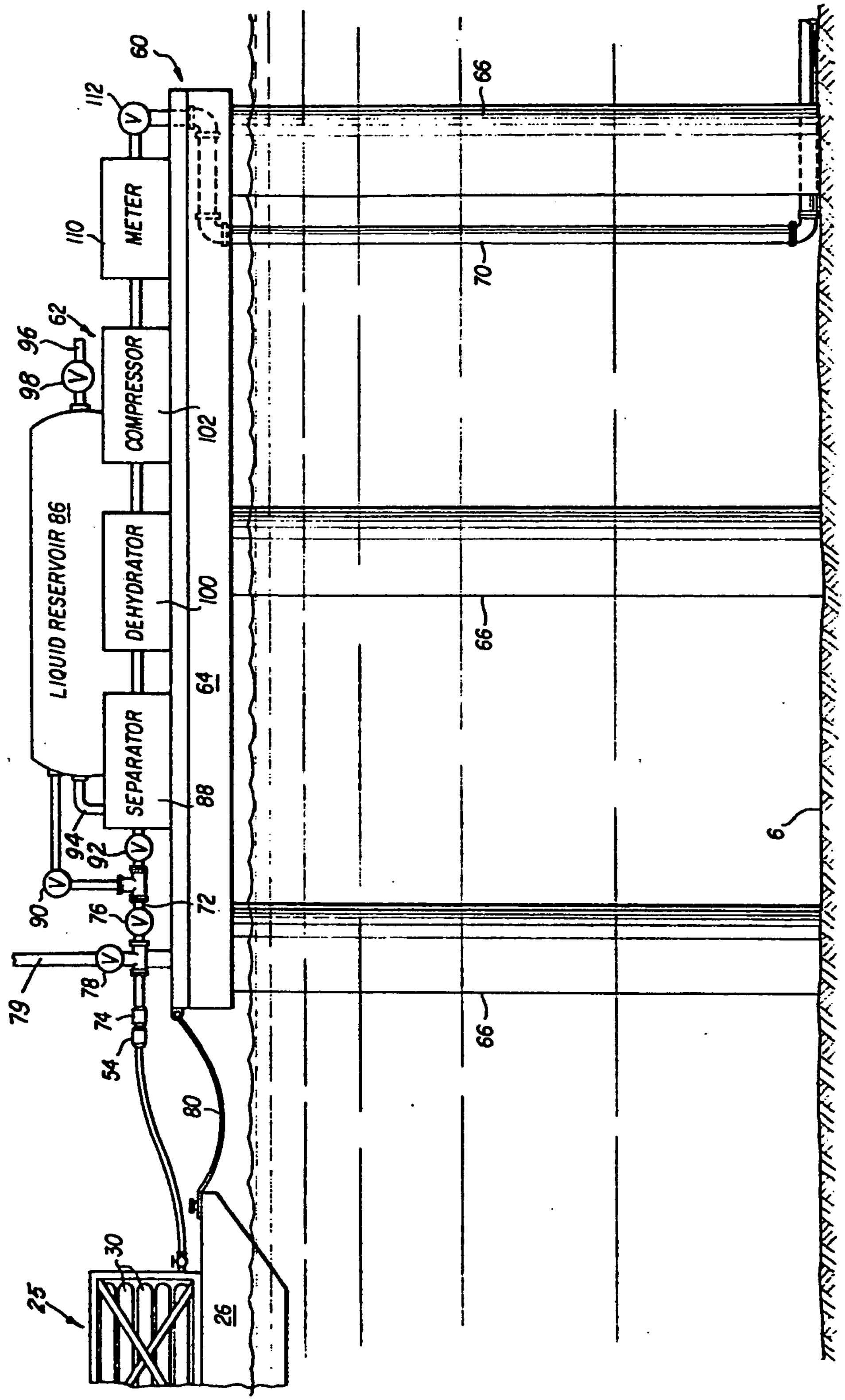
FIG. 2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V
METER
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96
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COMPRESSOR
102
LIQUID RESERVOIR 86
DEHYDRATOR
100
64
SEPARATOR
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94
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70
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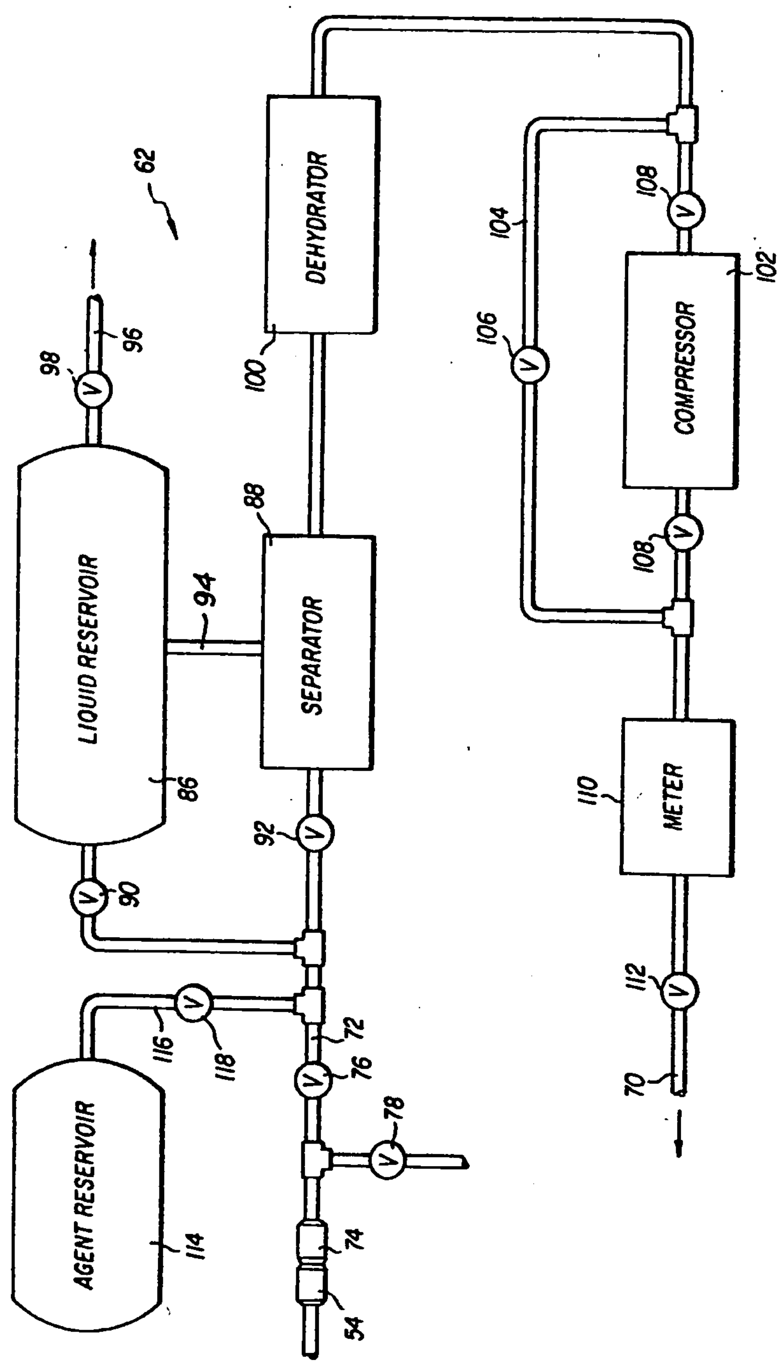
6

FIG. 3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SEPARATOR
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COMPRESSOR
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METER
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112
70

FIG. 4

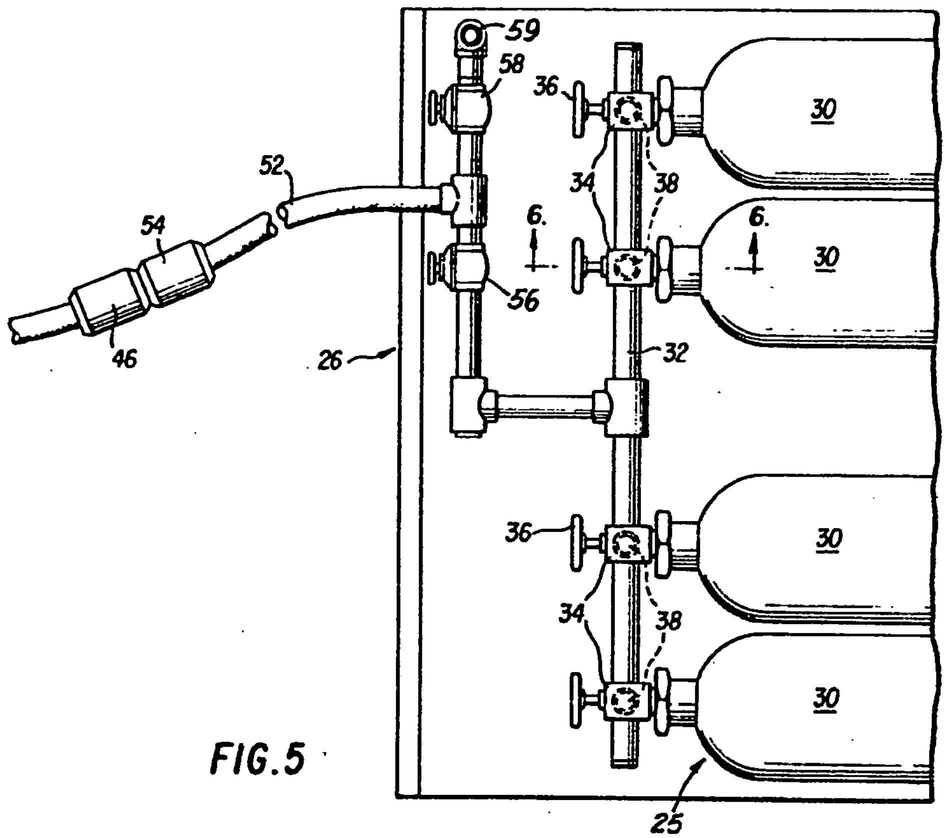
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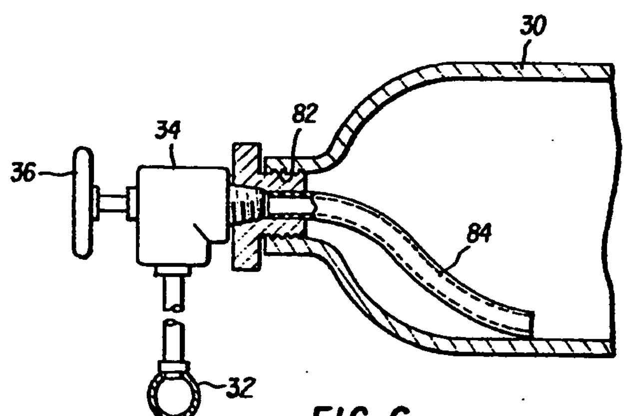
FIG.5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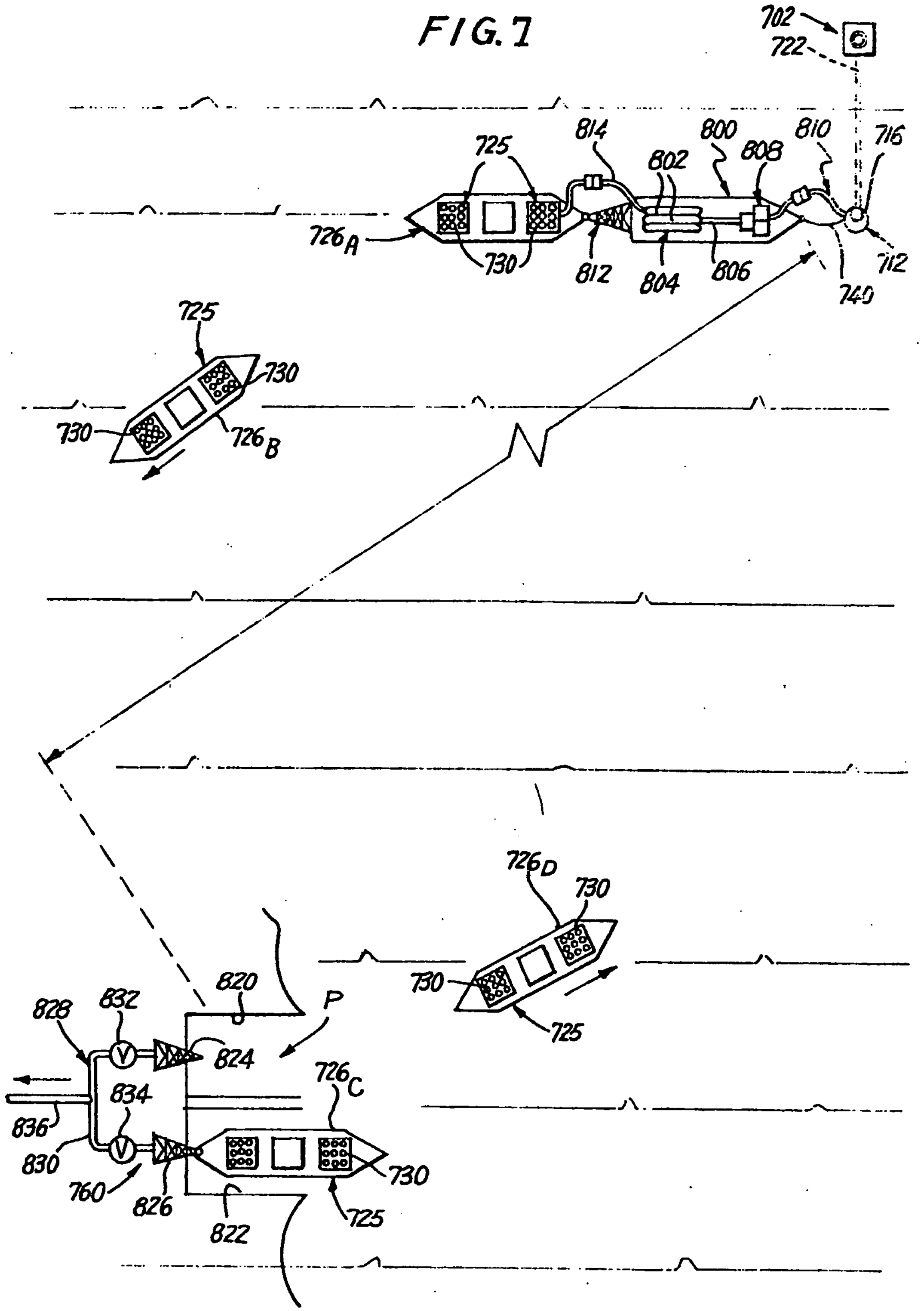
32

FIG.6

FIG. 7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726C
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725